

## 2.2 Water Quality

***Agricultural production often emits pollutants that affect the quality of the Nation's water resources and impose costs on water users. The extent and magnitude of agricultural pollution is difficult to assess because of its nonpoint nature. However, agriculture is the leading source of impairment in the Nation's rivers and lakes, and a major source of impairment to estuaries.***

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**P**roducing food and fiber involves many activities and practices that can affect the quality of water resources under and near the field. For example, tilling the soil and leaving it without plant cover for extended periods of time results in accelerated soil erosion. The use of chemical inputs increases the probability that some of these materials will wash off or leach through the field to enter water resources. Irrigation can move salt and other dissolved minerals to surface water. Livestock operations produce large amounts of waste which, if not properly disposed of, can threaten human health as well as contribute to excess nutrient problems in streams, rivers, and lakes.

### Quality of the Nation's Water

The Clean Water Act (passed in 1972 as the Federal Water Pollution Control Act) defines water quality in terms of designated beneficial uses with numeric and narrative criteria that support each use. Designated beneficial uses are the desirable uses that water resources should support. Examples are drinking water supply, primary contact recreations, and aquatic life support. Numeric water quality criteria establish the minimum physical, chemical, and biological parameters required for water to support a beneficial use. Physical and chemical criteria may set maximum concentrations of pollutants, acceptable ranges of physical parameters, and minimum concentrations of desirable parameters, such as

dissolved oxygen. Biological criteria describe the expected attainable community attributes and establish values based on measures such as species richness, presence or absence of indicator taxa, and distribution of classes of organisms (EPA, 1994). Narrative water quality criteria define conditions and attainable goals that must be maintained to support a designated use. Narrative biological criteria describe aquatic community characteristics expected to occur within a water body.

### Surface-Water Quality

The Nation's surface-water quality has improved since 1972, primarily through reductions in pollution from point sources. However, many water quality problems remain. Water Quality Inventories, published by the U.S. Environmental Protection Agency (EPA), show no major improvement in the quality of the Nation's rivers, lakes, ponds, and estuaries since 1990 (EPA, 1995). Agriculture is cited by States as a leading source of water quality impairment. A little over one-third of river miles, lake acres (excluding the Great Lakes), and estuarine waters assessed by the States were found to not fully support their designated uses in 1994 (table 2.2.1).

The Great Lakes continue to suffer serious pollution, even though some progress has been made in reducing the worst cases of nutrient enrichment

**Table 2.2.1—Status of the Nation's surface-water quality, 1988-94**

Item	Rivers				Lakes <sup>1</sup>				Estuaries			
	1988	1990	1992	1994	1988	1990	1992	1994	1988	1990	1992	1994
<i>Percent of total water</i>												
Water systems assessed	29	36	18	17	41	47	46	42	72	75	74	78
<i>Percent of assessed waters</i>												
Meeting designated uses:												
Supporting	70	69	62	64	74	60	56	63	89	67	68	63
Partially supporting	20	21	25	22	17	19	35	28	8	25	23	27
Not supporting	10	10	13	14	10	21	9	9	3	8	9	9
Clean Water Act goal of fishable:												
Meeting	86	80	66	69	95	70	69	69	97	77	78	70
Not meeting	11	19	34	31	5	30	31	31	3	23	22	30
Not attainable	3	1	-	-	-	0	-	-	0	-	0	0
Clean Water Act goal of swimmable:												
Meeting	85	75	71	77	96	82	77	81	92	88	83	85
Not meeting	11	15	20	23	4	18	22	19	1	12	17	15
Not attainable	4	10	9	-	-	-	-	-	7	-	0	-

- = less than 1 percent of assessed waters.

<sup>1</sup> Excluding Great Lakes.

Source: USDA, ERS, based on Environmental Protection Agency National Water Quality Inventories, 1988, 1990, 1992, 1994.

(particularly in Lake Erie). Only 3 percent of the assessed shoreline miles (with 96 percent assessed) fully support designated uses (EPA, 1995).

Sixty-three percent of the assessed shoreline does not support designated uses at all. Most of the Great Lakes shoreline is polluted with toxic organic chemicals, primarily PCB's and DDT that are often found in fish samples. Atmospheric deposition of toxics, including pesticides, and contaminated sediments are the leading sources of impairment.

The Chesapeake Bay, the largest estuary in the world, has seen water quality degrade over time because of agricultural development, population growth, and sewage treatment plant emissions. While an aggressive program has reduced phosphorus, nitrogen concentrations remain high, leaving the bay overenriched. Shellfish harvests have declined dramatically in recent years, and poor water quality is believed to be an important contributing factor.

Contaminated seafood and fishkills are also indicators of surface water quality. States issue fish consumption advisories to protect the public from

ingesting harmful quantities of toxic pollutants. All States but Alaska, South Dakota, and Wyoming issued fish consumption advisories in 1994, for a total of 1,531. This was up from 1,279 fish consumption advisories in 46 States in 1993 (EPA, 1994). Mercury, PCB's, chlordane, dioxin, and DDT caused more than 93 percent of the fish consumption advisories in 1994. These contaminants have been linked with human birth defects, cancer, neurological disorders, and kidney ailments. In addition, bacterial and viral contamination closed over 6,000 square miles of shellfish beds in 15 States during 1992-94. Most of the problems are from improperly treated sewage and urban runoff, but animal waste also contributes.

The number of fishkills provides some idea of pollutant impacts on aquatic life. These are most often sporadic events, rather than a chronic problem. Thirty-two States, tribes, and other jurisdictions reported 1,454 fishkill incidents during 1992-93 (EPA, 1995). Pesticides and manure/silage were identified by States as major contributors to fishkill incidents.

## Groundwater Quality

Some States report on the general quality of their groundwater resources in Section 305(b) reports. Of 38 States that reported overall groundwater quality in 1992, 29 judged their groundwater quality to be good or excellent (EPA, 1994). Generally, States report that degradation of groundwater resources is a local occurrence. Agriculture was cited as a source in 44 of the 49 States that reported major sources of groundwater contamination.

An indication of agriculture's impact on groundwater quality comes from the EPA's National Survey of Pesticides in Drinking Water Wells, conducted in 1988-90. The survey provided the first national estimates of the frequency and concentrations of pesticides and nitrate in community water system wells and rural domestic drinking water wells. (Results of this survey are reported in following sections.) In summary, the proportion of wells found to contain any particular pesticide or pesticide degradate was low. However, many wells were affected by the presence of nitrate at levels exceeding EPA health guidelines.

## Agricultural Pollutants

Agricultural production produces a wide variety of pollutants. These include sediment, nutrients, pesticides, salts, and pathogens. While farmers do not intend for these materials to move from the field to water resources, they often do. For example, as much as 15 percent of the nitrogen fertilizer and up to 3 percent of pesticides applied to cropland in the Mississippi River Basin makes its way into the Gulf of Mexico (Goolsby and Battaglin, 1993). States reported that agriculture is the leading remaining source of impairment in the Nation's rivers and lakes, and a major source of impairment in estuaries (EPA, 1995). An estimated 71 percent of U.S. cropland (nearly 300 million acres) is located in watersheds where the concentration of at least one of four common surface-water contaminants (nitrate, phosphorus, fecal coliform bacteria, and suspended sediment) exceeded generally accepted criteria in 1989 (Smith, Schwarz, and Alexander, 1994).

### Sediment

Disturbing the soil through tillage and cultivation and leaving it without vegetative cover increases the rate of soil erosion. Dislocated soil particles can be carried in runoff water and eventually reach surface water resources, including streams, rivers, lakes, reservoirs, and wetlands. Sediment causes various damage to water resources and to water users.

**Table 2.2.2—Trends in concentrations of agricultural water pollutants in surface waters, 1980-90**

Water resources region	Nitrate	Phosphorus	Suspended sediment
<i>Average percentage change per year</i>			
North Atlantic	*	-1.4	-0.4
South Atlantic-Gulf	*	0.1	0.2
Great Lakes	*	-3.3	0.5
Ohio-Tennessee	*	-1.0	-1.3
Upper Mississippi	-0.4	-1.2	-1.3
Lower Mississippi	-1.6	-3.8	-1.2
Souris-Red-Rainy	*	-0.8	1.2
Missouri	*	-1.7	-0.2
Arkansas-White-Red	*	-3.1	-0.7
Texas-Gulf-Rio Grande	*	-0.9	-0.6
Colorado	*	-2.4	-0.8
Great Basin	*	-2.7	-0.2
Pacific Northwest	*	-1.7	-0.1
California	*	-1.4	-0.6

\* Between -0.1 and 0.1.

Source: USDA, ERS, based on Smith, Alexander, and Lanfear, 1993.

Accelerated reservoir siltation reduces the useful life of reservoirs. Sediment can clog roadside ditches and irrigation canals, block navigation channels, and increase dredging costs. By raising stream beds and burying streamside wetlands, sediment can increase the probability and severity of floods. Suspended sediment can increase the cost of water treatment for municipal and industrial water uses. Sediment can also destroy or degrade aquatic wildlife habitat, reducing diversity and damaging commercial and recreational fisheries.

Siltation is one of the leading pollution problems in U.S. rivers and streams and among the top four problems in lakes and estuaries (EPA, 1995). Sediment damages from erosion have been estimated to be between \$2 billion and \$8 billion per year (Ribaud, 1989). These include damages or costs to navigation, reservoirs, recreational fishing, water treatment, water conveyance systems, and industrial and municipal water use.

Soil conservation efforts over the past 10 years, particularly the Conservation Reserve Program and Conservation Compliance, are starting to pay off (see

chapters 6.2 and 6.3). The National Resources Inventory reports that the average rate of sheet and rill erosion on cropland declined by about one-third between 1982 and 1992. In most regions of the country, the U.S. Geological Survey (USGS) found that suspended sediment concentrations trended slightly downward over the 1980's, particularly in the Ohio-Tennessee, and Upper and Lower Mississippi regions (table 2.2.2) (Smith, Alexander, and Lanfear, 1993). Areas characterized by corn and soybean production and mixed crops had the greatest downward trends.

### **Nutrients**

Nutrients can enter water resources three ways.

*Runoff* transports pollutants over the soil surface by rainwater or irrigation water that does not soak into the soil. Nutrients move from fields to surface water while dissolved in runoff water or adsorbed to eroded soil particles. *Run-in* transports chemicals directly to groundwater through sinkholes or porous or fractured bedrock. *Leaching* is the movement of pollutants through the soil by percolating rain or irrigation water. Soil organic matter content, clay content, and permeability all affect the potential for nutrients in soils to leach through the root zone.

Important nutrients from a water quality standpoint are nitrogen and phosphorus. Nitrogen, primarily found in the soil as nitrate, is easily soluble and is transported in surface runoff, in tile drainage, or with leachate. Phosphorus, primarily in the form of phosphate, is only moderately soluble and, relative to nitrate, is not very mobile in soils and ground water. However, erosion can transport considerable amounts of suspended phosphorus to surface waters.

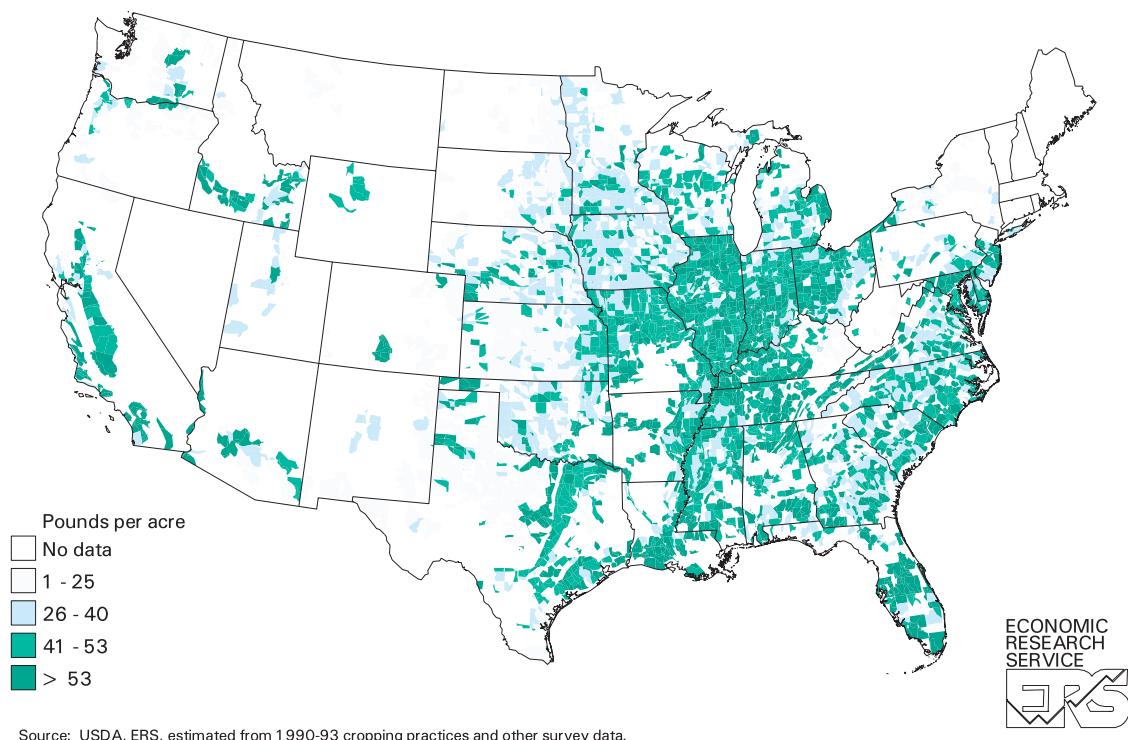
Nutrients from agriculture can accelerate algal production in receiving surface water, resulting in a variety of water-quality problems, including clogged pipelines, fishkills, and reduced recreation opportunities. Nitrate is the only nutrient for which the EPA has established a maximum contaminant level (MCL, a legal maximum long-term exposure) in drinking water (10 mg/L). Nitrate can be converted to nitrite in the gastrointestinal tract. In infants under 6 months of age, this nitrite could cause methemoglobinemia, otherwise known as "blue-baby syndrome," which prevents the transport of sufficient oxygen in the bloodstream. The presence of nitrate in concentrations above 10 mg/L in sources of public drinking water systems requires additional treatment, with associated treatment costs.

EPA reports that nutrient pollution is the leading cause of water quality impairment in lakes and estuaries, and is the third leading cause in rivers (1995). Agriculture is the primary source of nutrients in impaired surface waters.

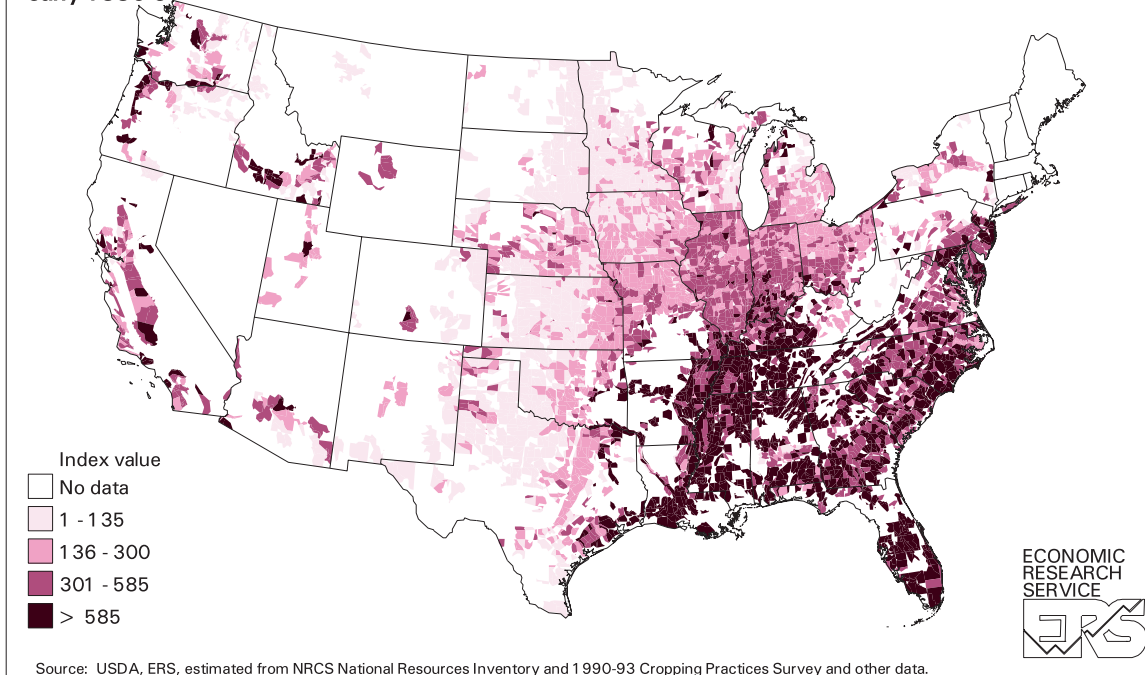
From its 1988-90 national survey of drinking water wells, the EPA found nitrate in more than half of the 94,600 community water system (CWS) wells and almost 60 percent of the 10.5 million rural domestic wells, making nitrate the most frequently detected chemical in well water. However, only 1.2 percent of the CWS's and 2.4 percent of the rural domestic wells were estimated to contain levels above the MCL. About 3 million people (including 43,500 infants) using water from CWS's and about 1.5 million people (including 22,500 infants) using rural wells are exposed to nitrate at levels above the MCL (EPA, 1992). Higher findings for rural domestic wells are expected since they are closer to farmland and are generally shallower than wells used by CWS's, making them more susceptible to contamination. More recently, the USGS found that the MCL was exceeded in about 1 percent of CWS's, but 9 percent of rural domestic wells (Mueller and others, 1995). The difference with EPA's findings is probably due to different sampling strategies. The USGS found that about 21 percent of wells under agricultural land exceeded the MCL in selected watersheds, with particularly high proportions exceeding the MCL in the Northern Plains (35 percent) and the Pacific (27 percent) regions.

Residual nitrogen is that portion of nitrogen available from natural and manmade sources that is not taken up by crops. Residual nitrogen on cropland (nitrogen from both commercial and manure sources in excess of plant needs) is an indicator of potential nitrate availability for runoff to surface water or leaching to ground water. Regions with relatively high residual nitrogen include the Corn Belt, parts of the Southeast, and the intensively irrigated areas of the West (fig. 2.2.1). However, residual nitrogen by itself does not necessarily result in water quality problems. For example, warm, moist soil conditions in the Southeast tend to volatilize residual nitrogen to the atmosphere, and vegetative buffers capture excess nitrogen before it reaches water systems (Mueller and others, 1995). Therefore, nitrate levels in surface and ground water in the Southeast tend to be low, even though the vulnerability index and residual applications may be high. Regions with the greatest potential for nitrate contamination of groundwater include parts of the Lower Mississippi River, Southeast, and intensively irrigated areas of the West, reflecting areas of heavy

**Figure 2.2.1--Residual soil nitrogen including nitrogen from manure, early 1990's**



**Figure 2.2.2--Groundwater vulnerability index for nitrogen including nitrogen from manure, early 1990's**



use and/or areas with soils prone to leaching (fig. 2.2.2). A similar index is not available for surface water. However, areas with high residual nitrogen and low groundwater vulnerability are more likely to have a high surface-water vulnerability.

Agricultural activities are not the only cause of nutrient pollution. Other sources of nitrogen and phosphorus include point sources such as wastewater treatment plants, industrial plants, and septic tanks. Atmospheric deposition is another nonpoint source of nitrogen. Indeed, more than half the nitrogen emitted into the atmosphere from fossil fuel-burning plants, vehicles, and other sources is deposited on U.S. watersheds (Puckett, 1994). The relative shares of point and nonpoint sources vary by region, with commercial agricultural fertilizers the dominant source in some areas of the West, and in the central and southeastern United States (Puckett, 1994). Nitrogen discharges from point sources, based on National Pollution Discharge Elimination System permits, are concentrated in the Northeast, Lake States, and Appalachian regions, areas with major population centers and large concentrations of industry (fig. 2.2.3). Areas that may have to deal with both point and nonpoint sources include the eastern Corn Belt, the agricultural areas of California, parts of the Southeast, and the Mid-Atlantic region (including Chesapeake Bay).

USGS analysis of nutrients in surface waters over the 1980's shows different trends for nitrate and phosphorus in surface water (table 2.2.2) (Smith, Alexander, and Lanfear, 1993). Nitrate, in general, showed no statistically significant trend, which differs from the rise noted during 1974-81. This follows the pattern of agricultural nitrogen use, which rose sharply during the 1970's, peaked in 1981, and then stabilized. Phosphorus in water during the 1980's continued a decline noted in the 1970's, likely due to improved wastewater treatment, decreased phosphorus content of detergents, reduced phosphorus fertilizer use, and reduced soil erosion. Indeed, the rate of phosphorus decline in water in cropland areas was more than twice that in urban areas.

### ***Pesticides***

A wide variety of pesticides, with different levels of toxicity, solubility, and persistence, are applied to agricultural crops to control pests, fungus, and disease (see chapter 3.2, *Pesticides*). Pesticides are extremely important to production, but their use and/or misuse may lead to water quality problems. Pesticides move to water resources much as nutrients do. In addition, some pesticides can be carried into the air attached to

dust or as an aerosol, and deposited into water bodies with rainfall.

Pesticide residues reaching surface-water systems may harm freshwater and marine organisms, damaging recreational and commercial fisheries. Pesticides in drinking water supplies pose risks to human health. Some commonly used pesticides have been identified as probable or possible human carcinogens. The presence of regulated pesticides above specified levels in water supplies requires additional treatment, placing added costs on water utilities and their customers. Enforceable drinking water standards have been established for 15 currently used pesticides, and more are pending (see box, "Maximum Contaminant Levels").

Well over 500 million pounds (active ingredient) of pesticides are applied annually on farmland (see chapter 3.2, *Pesticides*), and certain chemicals can travel far from where they are applied (Smith, Alexander, and Lanfear, 1993; Goolsby and others, 1993). Their presence in food and water has been highlighted and made an issue by environmental and consumer safety groups.

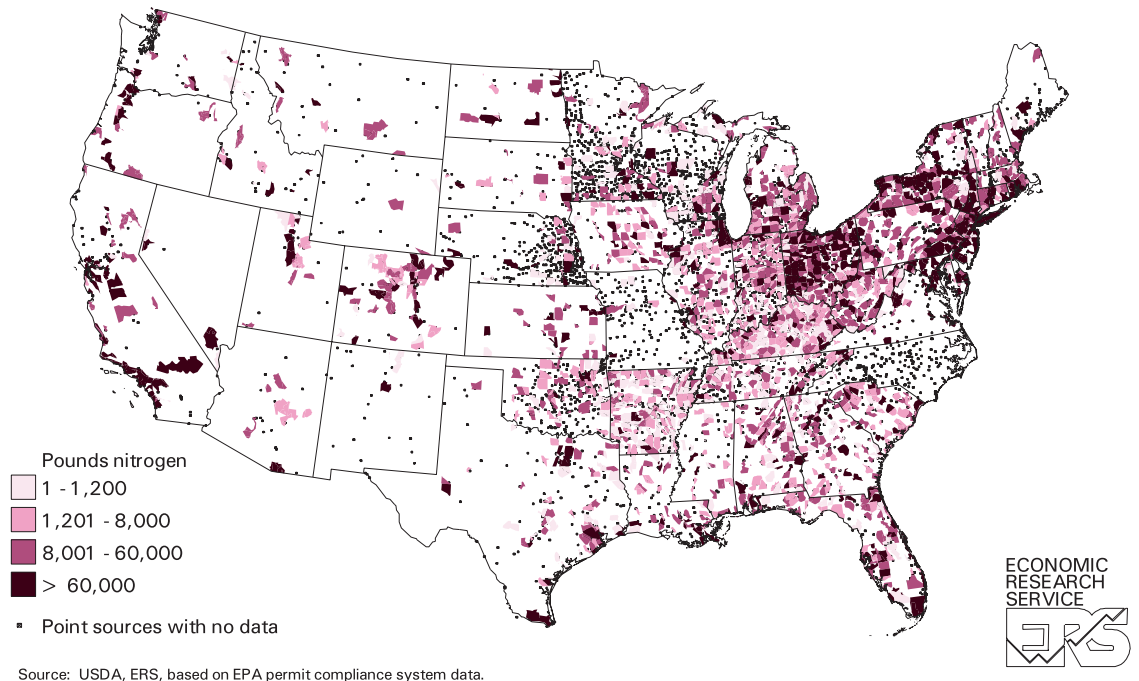
### **Maximum Contaminant Levels (MCL's)**

Public Water Systems are required to make sure that the water they supply does not exceed the MCL for each chemical. These are enforceable standards, set by EPA, that are considered feasible and safe. MCL's have been set for 15 agricultural chemicals.

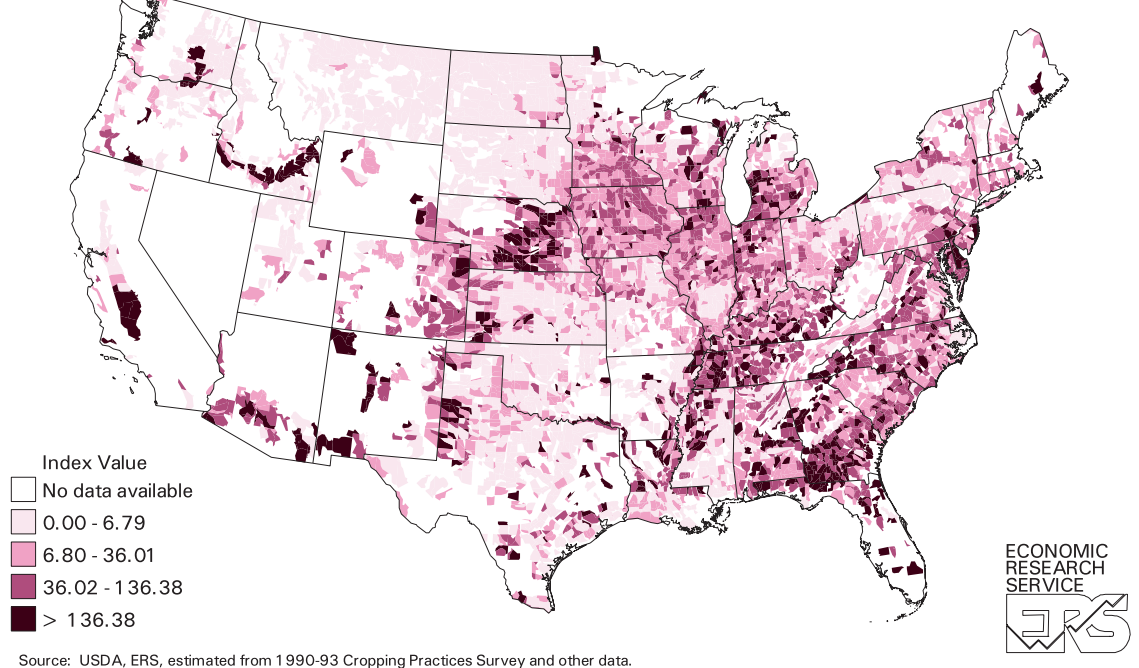
<u>Chemical</u>	<u>MCL (mg/l)</u>	<u>Type chemical</u>
Nitrate	10.0	fertilizer
Alachlor	.002	herbicide
Atrazine	.003	herbicide
Carbofuran	.04	insecticide
2,4-D	.07	herbicide
Dalapon	.2	herbicide
Dinoseb	.007	herbicide
Diquat	.02	herbicide
Endothall	.1	other
Glyphosate	.7	herbicide
Lindane	.0002	insecticide
Methoxychlor	.04	insecticide
Oxamyl	.2	insecticide
Picloram	.5	herbicide
Simazine	.004	herbicide



**Figure 2.2.3--Nitrogen from point sources (excluding confined animal operations), 1993**



**Figure 2.2.4--Groundwater vulnerability index for pesticides weighted by persistence and toxicity of pesticides, early 1990's**



Areas with low pesticide use usually have low detection frequencies (Barbash and Resek, 1995). Conversely, areas where a pesticide is detected frequently are often those of high use. However, low frequencies of pesticide detection are often encountered in areas of high use, indicating that other factors influence pesticide movement.

Most studies of pesticides in surface water focus on the midcontinent region where large amounts of pesticides are used. Goolsby and others (1993) found that herbicides are detected at low levels throughout the year in the rivers of the Midwest, including the Mississippi River. The amounts transported by streams and rivers in the Midwest are generally less than 3 percent of the amount applied, but can still result in concentrations above the MCL. Atrazine (and its metabolites), alachlor, cyanazine, and metolachlor, used principally for weed control in corn and soybeans, were the principal contaminants detected, and are also the most widely used pesticides in the region. Such chemicals, once in drinking water supplies, are not controlled by conventional treatment technologies (Miltner and others, 1989). About 21 million people in the Midwest rely on drinking water from surface sources, about 42 percent of the population.

High concentrations of atrazine in some water supplies in the Midwest have prompted concerns that public water utilities will have to install expensive water treatment systems in order to meet Safe Drinking Water Act requirements. In 1990, about 29 percent of public utilities dumped powdered activated carbon into their systems to spot-treat for organic chemicals, primarily pesticides (American Water Works Association, 1992). If all the treatment plants withdrawing from surface sources upgrade their treatment systems to remove pesticides, annual treatment costs would increase by \$400 million per year (Ribaud and Bouzaher, 1994). Because of these concerns, EPA has placed the triazine herbicides (atrazine, cyanazine, and simazine) under special review due to potential health and ecological concerns. DuPont has already announced that it will phase out its cyanazine production.

Some pesticides leach into underlying aquifers. EPA's survey of drinking water wells found that 10 percent of the CWS's and 4 percent of rural domestic wells contained at least one pesticide (1990). Pesticides or their transformation products have been detected in the ground waters of 43 States (Barbash and Resek, 1995). However, the EPA estimated that less than 1 percent of the CWS's and rural domestic wells had

concentrations above MCL's or Lifetime Health Advisory Levels (the maximum concentration of a water contaminant that may be consumed safely over an average lifetime). Problems were found more frequently in shallow wells in agricultural areas. A sampling of wells in corn- and soybean-growing areas in the Midwest found 28 percent of wells had detectable levels of selected pesticides and metabolites, but none exceeded the MCL (Kolpin, Burkart, and Thurman, 1993). Atrazine was the most frequently detected compound.

Groundwater vulnerability to pesticides varies geographically, depending on soil characteristics, pesticide application rates, and the persistence and toxicity of the pesticides used (fig. 2.2.4) (see chapter 3.2, *Pesticides*, for more discussion of persistence and toxicity). Areas with sandy, highly leachable soils, such as central Nebraska and the blueberry barrens of Maine, have high vulnerability ratings. Highly vulnerable areas characterized by heavy applications of generally toxic materials on fruit and vegetable crops include the San Joaquin Valley in California, Florida, and southern Arizona. In contrast, the Corn Belt, despite the widespread use of chemicals, particularly herbicides, has a lower rating than other areas because the predominant soils are not prone to leaching.

### **Animal Waste**

Animal operations can generate large amounts of waste which, if improperly handled or disposed of, can affect the quality of surface- and groundwater resources. Improperly constructed storage pits or lagoons at confined facilities can break or leak, releasing large amounts of concentrated waste directly into surface water. Dissolved material can leach into groundwater if lagoons or pits are improperly lined. Pastured animals allowed to graze near or to water in streams can contaminate water. Improper application of animal waste on fields, such as spreading on frozen ground, can result in large amounts being flushed into water bodies after rain or a thaw.

An issue of increasing importance to water quality is the management of manure from confined animal operations. This stems from increasing concentration in the animal industry, a number of incidents where manure has contaminated local water bodies (see box "Animal Waste Storage Failures"), and a greater awareness of the potential for contamination of drinking water supplies by waste-borne parasites. Larger operations, particularly for hogs and dairy cows, now characterize the industry. As animal production units grow increasingly large and



## Animal Waste Storage Failures

The growing concerns over concentrated animal operations were highlighted when a dike around a large hog-waste lagoon in North Carolina failed, releasing an estimated 25 million gallons of hog waste (twice the volume of the oil spilled by the Exxon Valdez) into nearby fields, streams, and the New River. The 8-acre earthen lagoon was built to allow microbes to digest the waste, and is a common form of management for confined operations. The spill killed virtually all aquatic life in the 17-mile stretch between Richlands and Jacksonville, NC.

There are approximately 6,000 confined animal operations with at least 1,000 animal units in the United States. (One animal unit equals 1 beef animal, 0.7 dairy cow, 2.5 hogs, 18 turkeys, or 100 chickens.) Under the Clean Water Act, these facilities cannot discharge to waters except in the event of a 25-year/24-hour storm. This requirement necessitates the construction of onsite storage facilities for holding manure and runoff. In addition to these large operations, facilities with more than 300 animal units that discharge directly to waters are required to take the same measures. Regions with large numbers of animal operations containing more than 1,000 animal units include the Northern Plains (for beef), Pacific (dairy), Corn Belt (swine), Appalachian (swine), and Southeast (broilers).

Most States are responsible for carrying out Clean Water Act regulations. A survey of livestock waste control programs in 10 Midwest and Western States indicated that few States actively inspect facilities for problems, including the integrity of storage structures (Iowa Dept. Nat. Res., 1990). National estimates of broken or leaking storage facilities do not exist. However, a North Carolina State University study estimated that wastes were leaking from half of North Carolina's lagoons built before 1993 (Satchell, 1996), so the problem may be widespread.

specialized, they tend to lack sufficient cropland on which manure can be spread. Without adequate cropland, larger and more sophisticated manure handling and storage systems are required. Improper management, equipment failure, or unusual rainstorms can cause serious water quality problems.

Animal waste contains a number of pollutants. Waste can contain significant amounts of nitrogen and phosphorus. These nutrients pose the same concerns about eutrophication and methemoglobinemia as inorganic sources. In addition, fish and other aquatic organisms may die from ammonia produced as manure decays, or they may suffocate due to insufficient oxygen levels caused by the oxygen-demanding decomposition of organic matter in the manure.

Nitrogen from animal waste is an important source of total nitrogen loads in some parts of the country. Many areas have high ratios of nitrogen from manure on confined animal operations to the operations' land available for spreading (see chapter 4.5, *Nutrient Management*). The highest ratios of nitrogen to land are found in parts of the Southeast, Delta, and Southwest. Studies in 16 watersheds found that manure was the largest nitrogen source in 6, primarily in the Southeast and Mid-Atlantic States (Puckett, 1994).

Animal waste also contains pathogens that pose a threat to human health. Up to 150 diseases from the microorganisms in livestock waste can be contracted through direct contact with contaminated water, consumption of contaminated drinking water, or consumption of contaminated shellfish. Some illnesses that can be contracted from animal waste include cholera, tuberculosis, typhoid fever, salmonella, and polio. Parasites of concern include cryptosporidium and giardia.

Outbreaks of cryptosporidia, a parasite found in the feces of some animals and that causes gastrointestinal illness, are causing growing concern over the safety of water supplies in areas with large numbers of cattle. This organism has been implicated in gastroenteritis outbreaks in Milwaukee, Wisconsin (400,000 cases and 100 deaths in 1993) and in Carrollton, Georgia (13,000 cases in 1987). The cost of the Milwaukee outbreak is estimated to exceed \$54 million (*Health and Environment Digest*, 1994). While the source of the organism in these outbreaks was never determined, its incidence in many dairy herds has brought some attention to this sector, especially given the proximity of dairies to population centers.

### **Salinity**

Irrigation return flows can carry dissolved salts, as well as nutrients and pesticides, into surface- or

groundwater. Dissolved salts and other minerals can have significant impacts on surface- and groundwater quality. Increased concentrations of naturally occurring toxic minerals, such as selenium and boron, can harm aquatic wildlife and degrade recreation opportunities. Increased levels of dissolved solids in public drinking water supplies can increase water treatment costs, force the development of alternative water supplies, and reduce the lifespans of water-using household appliances. Increased salinity levels in irrigation water can reduce crop yields or damage soils so that some crops can no longer be grown.

Dissolved salts and other minerals are an important cause of pollution in the Southern Plains, arid Southwest, and southern California. Total damages from salinity in the Colorado River range from \$310 million to \$831 million annually, based on the 1976-85 average levels of river salinity. These include damages to agriculture (\$113-\$122 million), households (\$156-\$638 million), utilities (\$32 million), and industry (\$6-\$15 million) (Lohman, Milliken, and Dorn, 1988).

The USGS reports mixed trends of salinity in surface water (Smith, Alexander, and Lanfear, 1993). Measures of dissolved solids (mostly ions of calcium, magnesium, sodium, potassium, bicarbonate, sulfate, and chloride) indicate that water quality improved at more stations than it worsened. However, while salinity trends in water for domestic and industrial purposes generally improved during the 1980's, salinity worsened for irrigation purposes. Among USGS cataloguing units (watersheds) having significant irrigation surface-water withdrawals, the percentage of stations having annual average dissolved solids concentrations greater than 500 mg/L increased during 1980-89 from 30 to 33 percent.

### Reducing Loadings from Agriculture

Farmers can take many steps to reduce loadings of agricultural pollutants to water resources. Both structural and management practices are available to farmers. In a study of 16 of USDA's 242 Water Quality Program projects, 134 different practices were installed, nearly half of which were labeled "new and innovative" (USDA, NRCS, 1996). Water quality practices work by managing water and chemical inputs more efficiently, or by controlling runoff. Practices include pest management, nutrient management, irrigation water management, animal waste management, tillage management, and runoff control (for more on practices, see chapters 4.1-4.6).

### Groundwater Vulnerability Indexes

The groundwater vulnerability index for nitrates (GWVIN) was developed by Kellogg and others (1992). It is a function of soil leaching potential, nitrate leaching potential, precipitation, and nitrogen fertilizer use. Excess nitrogen per acre is the difference between the amount of nitrogen from commercial fertilizer and animal manure applied, including credit for nitrogen fixed by previous leguminous crops, and the amount taken up by the crop.

The groundwater vulnerability index for pesticides (GWVIP), also developed by Kellogg and others (1992), is a function of soil leaching potential, pesticide leaching potential, precipitation, and chemical use. It is an extension of the national-level Soil-Pesticide Interaction Screening Procedure (SPISP) developed by the Natural Resources Conservation Service (Goss and Wauchope, 1990). GWVIP does not depend on the amount of chemical applied, but the type of chemical, its leaching potential, and the leaching potential of the soil to which the chemical is applied. The GWVIP can be weighted by persistence and toxicity to further account for potential harm to the environment. Persistence is defined as the soil half-life. Toxicity is defined as the acute oral toxicity to rats. Chronic toxicity or toxicity to fish would have been preferred, but these data are not available for most pesticides. For further discussion of weighting for persistence and toxicity, see chapter 3.2, *Pesticides*.

USDA has had several programs that provide farmers the means to adopt water quality practices, including the Agricultural Conservation Program, Water Quality Incentive Projects, and the Water Quality Program. Most current programs focus on providing education, technical, and financial assistance to farmers to get them to adopt alternative management systems that protect water quality. Education raises farmer awareness not only of the potential financial and environmental benefits of alternative practices, but also of the link between the practices they implement and local water quality. Technical and financial assistance provide the means for a farmer to actually try a new practice and to acquire the skill to apply it effectively. Failure of voluntary programs to achieve needed changes in farming practices may increasingly result in regulations, already occurring in a number of States (see chapter 6.2, *Water Quality Programs*, for more on Federal and State programs).

Improvements in water quality from farmers' efforts to reduce pollutant loadings often take years to detect and document. The links between improved management and observed changes in water quality are complex. As many as 10 consecutive years of water quality data are needed before long-term changes can be distinguished from short-term fluctuations (Smith, Alexander, and Lanfear, 1993). Phosphorus accumulated in bottom sediments will affect water quality long after conservation practices have dramatically reduced phosphorus loadings in runoff. Similarly, fish, insects, and other biological indicators of a healthy stream may not reach acceptable levels until many years after water quality improves and riparian habitat is restored. Aquifers may take decades to show improvements in quality after chemical management is improved. In most project areas, agriculture is not the only source of pollution.

In addition, many projects do not establish or maintain adequate water quality monitoring for detecting changes in water quality. National water quality monitoring systems already in place are inadequate for detecting changes in small watersheds where water quality programs have generally been targeted. For these reasons, improvements in water quality may in fact be taking place undetected.

### **Costs and Benefits of Pollution Control**

The assessment of policies to reduce pollution from agricultural production requires a complete knowledge of benefits and costs to water users of changes in water quality. Benefits and costs are measured in terms of changes in economic welfare, represented by consumer and producer surpluses. Estimating the economic effects of changes in water quality is complicated by the lack of organized markets for environmental quality. There are no observed prices with which to measure economic value. A number of methods exist for deriving these measures. One method for estimating consumer surplus is to study an individual's behavior in averting the consequences of poor environmental quality, such as expenditures made to prevent household damages from salinity. A second approach is to exploit the relationship between private goods and environmental quality (when it exists) to draw inferences about the demand for environmental quality. A third approach is to ask individuals to reveal directly their willingness to pay for changes in environmental quality.

When water quality is a factor in the production of a market good, the benefits of changes in quality can be

inferred from changes in variables associated with the production of the market good. There are two avenues through which benefits can be obtained. The first is through changes in the price of the marketable good to consumers. The second is through changes in incomes received by owners of factor inputs. The choice of approaches for estimating consumer and produce welfare effects depends largely on the availability of data and the nature of demand for water quality.

Economists have conducted numerous studies of the value of water quality over the years. Most of these studies have focused on specific sites or "local" water quality issues (Crutchfield, Feather, and Hellerstein, 1995). Relatively few studies have looked at the costs of water pollution and the benefits of pollution reduction on a nationwide scale, and none have included costs to all classes of water users (table 2.2.3). However, the results of these studies indicate that the annual benefits from improving water quality could total tens of billions of dollars. Water quality benefits from erosion control on cropland alone could total over \$4 billion per year (Hrubovcak, LeBlanc, and Eakin, 1995).

Although increasing, public funds spent on nonpoint source pollution are small compared with the expenditures on point sources. Between \$80 and \$100 billion of public funding was spent on water pollution control during the 1980's (Ervin, 1995), mainly to control pollutants from municipal sources. In contrast, only \$1 to \$2 billion has been spent on agricultural water quality initiatives over the last two decades (Ervin, 1995). This spending is much less than the potential benefits from improved water quality. However, an increasing amount of financial and other resources is being directed to agricultural nonpoint source pollution. USDA spent \$194 million on water quality-related research, education, technical assistance, financial assistance, and data activities in 1995. Such expenditures have doubled since 1989, despite an overall decrease in USDA expenditures for conservation. Farmers themselves have spent an unknown amount on water quality practices, although in many cases changes were made to enhance profitability. In addition, EPA made over \$65 million in regional grant awards to States for agricultural nonpoint source programs in 1994-95, an increase of 50 percent over the previous 2-year period. These funds are frequently contracted to cooperating agencies such as local conservation districts to support project implementation. (For more information on water quality programs, see chapter 6.2.)

**Table 2.2.3—National estimates of the damages from water pollution or the benefits from water pollution control**

Study/year	Estimate of:	Description
Freeman (1982)	National benefits of water pollution control	Total damages to recreational water uses from all forms of pollution: \$1.8-\$8.7 billion, "best guess" of \$4.6 billion (1978 dollars per year).
Russell and Vaughan (1982)	National recreational fishing benefits from controlling water pollution	Total benefits of \$300-\$966 million, depending on level of pollution control instituted.
Clark et al. (1985)	National water quality damages from soil erosion on cropland	Damages to all uses: \$3.2-\$13 billion, "best guess" of \$6.1 billion (1980 dollars). Cropland's share of erosion-related damages: \$2.2 billion.
Ribaudo (1986)	Regional and national water quality benefits of reducing soil erosion	Erosion reductions from 1983 soil conservation programs implied \$340 million in offsite benefits. Benefits per ton of erosion reduced were from \$0.28 to \$1.50.
Nielsen and Lee (1987)	National costs of groundwater contamination	Monitoring costs for presence of agricultural chemicals put at \$890 million-\$2.2 billion for private wells, and \$14 million for public wells.
Ribaudo (1989)	Regional and national water quality benefits from the Conservation Reserve Program	Reducing erosion via retirement of 40-45 million acres of highly erodible cropland would generate \$3.5-\$4.5 billion in surface-water quality benefits over the life of the program.
Carson and Mitchell (1993)	National benefits of surface-water pollution control	Annual household willingness to pay for maximum water quality improvement of \$205-\$279 per household per year, or about \$29 billion nationally.
Feather and Hellerstein (1997)	National recreation benefits of soil erosion reductions	A total of \$286 million in benefits from erosion reductions on agricultural lands since 1982, based on data from a recreation survey.

Source: USDA, ERS, based on Crutchfield, Feather, and Hellerstein, 1995; and Feather and Hellerstein, 1996.

While regulations were used to reduce point sources, efforts to reduce nonpoint sources have primarily relied on voluntary measures. Analysis has shown that many of the management practices that reduce agricultural nonpoint source pollution are not costly to implement, and may even increase net returns (U.S. Congress, OTA, 1995). A highly targeted approach that emphasizes low-cost land management changes—and that is backed by sound science, technical and financial support, and regulations—would provide the best means of achieving most water quality goals.

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## References

- American Water Works Association (1992). *Water Industry Data Base: Utility Profile*. Denver, CO.
- Barbash, J.E., and E.A. Resek (1995). *Pesticides in Ground Water: Current Understanding of Distribution and Major Influences*. U.S. Geological Survey.
- Carson, R.T., and R.C. Mitchell (1993). "The Value of Clean Water: The Public's Willingness to Pay for Boat-able, Fishable, and Swimmable Water Quality," *Water Resources Research*, Vol. 29, No. 2, pp. 245-254.
- Clark, E.H., II, J.A. Haverkamp, and W. Chapman (1985). *Eroding Soils: The Off-Farm Impacts*. Washington, DC: The Conservation Foundation.
- Crutchfield, S.R., P.M. Feather, and D.R. Hellerstein (1995). *The Benefits of Protecting Rural Water Quality: An Empirical Analysis*. AER-701. U.S. Dept. Agr., Econ. Res. Serv., Jan.
- Ervin, D.E. (1995). "A New Era of Water Quality Management in Agriculture: From Best Management Practices to Watershed-Based Whole Farm Approaches," *Water Resources Update*. No. 101, pp. 18-28.
- Feather, P., and D. Hellerstein (1997). "Calibrating Benefit Function Transfer To Assess the Conservation Reserve Program," *American Journal of Agricultural Economics*. April.
- Freeman, A.M., III (1982). *Air and Water Pollution Control: A Benefit-Cost Assessment*. New York: John Wiley and Sons.
- Goolsby, D.A., and W.A. Battaglin (1993). "Occurrence, Distribution, and Transport of Agricultural Chemicals in Surface Waters of the Midwestern United States," in Goolsby, D.A., L.L. Boyer, and G.E. Mallard, *Selected Papers on Agricultural Chemicals in Water Resources of the Midcontinental United States*. Open-File Report 93-418, U.S. Geological Survey. pp. 1-25.

## Recent ERS Reports on Water Quality Issues

***Accounting for the Environment in Agriculture***, TB-1847, October 1995 (James Hrubovcak, Michael LeBlanc, and B. Kelly Eakin). Detailed information derived from the national income and product accounts provides the basis for economic interpretations of changes in the Nation's income and wealth. The effects of soil erosion on agricultural productivity and income, the economic effect of decreased water quality, and depletion of water stock are presented as examples of the potential scope of accounting adjustments needed in the agricultural sector.

***USDA's Water Quality Program Enters its 6th Year***, AREI Update, 1995, No. 11 (Marc Ribaud). Sixty-five water quality projects were started in 1995, and 6 projects were completed at the end of 1994. Over 400 water quality projects have been started since 1990.

***Voluntary Incentives for Reducing Agricultural Nonpoint Source Water Pollution***, AIB-716, May 1995 (Peter Feather and Joe Cooper). Data from the Area Studies are used to evaluate the success of existing incentive programs to control agricultural nonpoint source pollution. Because profitability drives production decisions, these programs tend to be most successful when they promote inexpensive changes in existing practices.

***The Benefits of Protecting Rural Water Quality: An Empirical Analysis***, AER-701, January 1995 (Stephen R. Crutchfield, Peter M. Feather, and Daniel R. Hellerstein). The use of nonmarket valuation methods to estimate the benefits of protecting or improving rural water quality from agricultural sources of pollution is explored. Two case studies show how these valuation methods can be used to include water-quality benefits estimates in economic analyses of specific policies to prevent or reduce water pollution.

***Atrazine: Environmental Characteristics and Economics of Management***, AER-699, September 1994 (Marc Ribaud and Aziz Bouzahr). Atrazine is an important herbicide in the production of corn and other crops in the United States. Recent findings indicate that elevated amounts of atrazine are running off fields and entering surface-water resources. The costs and benefits of an atrazine ban, a ban on pre-plant and pre-emergent applications, and a targeted ban to achieve a surface-water standard are examined.

***Cotton Production and Water Quality: Economic and Environmental Effects of Pollution Prevention***, AER-664, December 1992 (Stephen Crutchfield, Marc Ribaud, LeRoy Hansen, and Ricardo Quiroga). The most widespread potential water-quality problems from cotton production are nitrate leaching and losses of pesticides to surface waters. Alternative policies for reducing these types of pollution are evaluated.

***Estimating Water Quality Benefits: Theoretical and Methodological Issues***, TB-1808, September 1992 (Marc Ribaud and Daniel Hellerstein). Knowledge of the benefits and costs to water users is required for a complete assessment of policies to create incentives for water quality-improving changes in agricultural production. A number of benefit estimation methods are required to handle the varying nature of water quality effects.

***Water Quality Benefits from the Conservation Reserve Program***, AER-606, February 1989 (Marc Ribaud). The Conservation Reserve Program was estimated to generate between \$3.5 and \$4 billion in water quality benefits if it achieves its original enrollment goal of 40-45 million acres. Potential benefits include lower water treatment costs, lower sediment removal costs, less flood damage, less damage to equipment that uses water, and increased recreational fishing.

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Goolsby, D.A., E.M. Thurman, M.L. Pomes, M. Meyer, and W.A. Battaglin (1993). "Occurrence, Deposition, and Long Range Transport of Herbicides in Precipitation in the Midwestern and Northeastern United States," in Goolsby, D.A., L.L. Boyer, and G.E. Mallard, *Selected Papers on Agricultural Chemicals in Water Resources of the Midcontinental United States*. Open-File Report 93-418, U.S. Geological Survey. pp. 75-88.

Goss, D.W., and D. Wauchop (1990). "The SCS/ARS/CES Pesticide Properties Database: II, Using it With Soils Data in a Screening Procedure," in D.L. Weigman (ed.), *Pesticides in the Next Decade: The Challenges Ahead*, Virginia Water Resources Research Center, Blacksburg, Virginia, pp. 471-493.

*Health and Environment Digest* (1994). "Cryptosporidium and Public Health," Vol. 8, No. 8. pp. 61-63.

- Iowa Dept. of Natural Resources (1990). "Livestock Waste Control Programs of Ten Midwest and Western States," Environmental Protection Division, Nov.
- Hrubovcak, J., M. LeBlanc, and B.K. Eakin (1995). *Accounting for the Environment in Agriculture*. TB-1847. U.S. Dept. Agr., Econ. Res. Serv., Oct.
- Kellogg, R.L., M.S. Maizel, and D.W. Goss (1992). *Agricultural Chemical Use and Ground Water Quality: Where Are the Potential Problem Areas?* U.S. Dept. Agr., Soil Cons. Serv., Econ. Res. Serv., Coop. State. Res. Serv., and Nat. Cent. for Resource Innovations.
- Kolpin, D.W., M.R. Burkart, and E.M. Thurman (1993). *Hydrogeologic, Water-Quality, and Land-Use Data for the Reconnaissance of Herbicides and Nitrate in Near-Surface Aquifers of the Midcontinental United States, 1991*. Open-File Report 93-114. U.S. Geological Survey.
- Lohman, L.C., J.G. Milliken, and W.S. Dorn (1988). *Estimating Economic Impacts of Salinity of the Colorado River*. U.S. Dept. of the Interior, Bureau of Reclamation. Feb.
- Miltner, R.J., D.B. Baker, T.F. Speth, and C.A. Fronk (1989). "Treatment of seasonal pesticides in surface waters," *American Water Works Journal*, Vol. 81, No.1, pp. 43-52.
- Mueller, D.K., P.A. Hamilton, D.R. Helsel, K.J. Hitt, and B.C. Ruddy (1995). *Nutrients in Ground Water and Surface Water of the United States - An Analysis of Data Through 1992*. Water-Resources Investigations Report 95-4031. U.S. Dept. of the Interior, Geological Survey.
- Nielsen, E.G., and L.K. Lee (1987). *The Magnitude and Costs of Groundwater Contamination from Agricultural Chemicals*. AER-576. U.S. Dept. Agr., Econ. Res. Serv., Oct.
- Puckett, L.J. (1994). *Nonpoint and Point Sources of Nitrogen in Major Watersheds of the United States*. Water-Resources Investigations Report 94-4001. U.S. Dept. of the Interior, Geological Survey.
- Ribaudo, M.O. (1989). *Water Quality Benefits from the Conservation Reserve Program*. AER-606. U.S. Dept. Agr., Econ. Res. Serv., Feb.
- Ribaudo, M.O. (1986). *Reducing Soil Erosion: Offsite Benefits*. AER-561. U.S. Dept. Agr., Econ. Res. Serv., Sept.
- Ribaudo, M.O., and A. Bouzaher (1994). *Atrazine: Environmental Characteristics and Economics of Management*. AER-699. U.S. Dept. Agr., Econ. Res. Serv., Sept.
- Russell, C.S., and W.J. Vaughan (1982). "The National Recreational Fishing Benefits of Water Pollution Control." *Journal of Environmental Economics and Management*, Vol. 9 pp. 328-354.
- Satchell, M. (1996). "Hog heaven—and hell," *U.S. News & Word Report*, Jan. 22, pp. 55-59.
- Smith, R.A., G.E. Schwarz, and R.B. Alexander (1994). *Regional Estimates of the Amount of U.S. Agricultural Land Located in Watersheds with Poor Water Quality*. Open-File Report 94-399. U.S. Dept. of the Interior, Geological Survey.
- Smith, R.A., R.B. Alexander, and K.J. Lanfear (1993). "Stream water quality in the conterminous United States - Status and trends of selected indicators during the 1980's," in U.S. Dept. of the Interior, Geological Survey, *National Water Summary 1990-91: Hydrologic Events and Stream Water Quality*. Water-Supply Paper 2400. pp. 111-140.
- U.S. Congress, Office of Technology Assessment (1995). *Targeting Environmental Priorities in Agriculture: Reforming Program Strategies*. OTA-ENV-640. Sept.
- U.S. Department of Agriculture, Natural Resources Conservation Service (1996). *Physical Impacts of Selected USDA Demonstration and Hydrologic Unit Area Water Quality Projects: Final Assessment Report* (draft). Feb.
- U.S. Environmental Protection Agency (1992). *Another Look: National Survey of Pesticides in Drinking Water Wells, Phase II Report*. EPA 579/09-91-020, Jan.
- U.S. Environmental Protection Agency (1990). *National Pesticide Survey Phase I Report*. EPA 570/9-90-003, Sept.
- U.S. Environmental Protection Agency (1992). *National Water Quality Inventory: 1990 Report to Congress*. EPA 503-9-92-006, Apr.
- U.S. Environmental Protection Agency (1994). *The Quality of Our Nation's Water: 1992*. EPA 841-S-94-002, March.
- U.S. Environmental Protection Agency (1995). *National Water Quality Inventory: 1994 Report to Congress Executive Summary*. Dec.